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Visualizing Non-Physical, Logical Constructs for Command Decision Support

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MOTIVATION

The motivation for this Provocation Topic presentation is directly related to existing critical issues and challenges in both the Data Fusion and Visualization communities. Both of these communities are wrestling with the meanings (ontologies) of, and means for visualization of what we are calling "logical constructs", or constructs that have relevant semantic meaning in an application context but do not correspond to an observable, measurable reality in the real world. Such constructs correspond to what the Data Fusion community calls "Level 2" and "Level 3" processing, processes that produce results which are called "situations", "threats", "intentions", "operational readiness" and the like. Limited research in the Data Fusion community at these Levels has resulted in a generally poor and unstructured understanding of what these constructs really are and how they might be ontologically structured and related to one another. Even if such definitions and categorizations were known, there is the subsequent question of how to communicate these mental constructs to a human such that they can be "seen in the mind", as described in the Call for Participation.

The reason these issues are important is that these "logical constructs" are the informational states around which higher-level command decision-making occurs; e.g., force-level maneuver decisions will depend on fused estimates of a hostile "threat" state, whereas lower-echelon decisions such as to shoot at a specific target depend instead on fused estimates of a physical target's location in space, corresponding to a physical reality. Without formalized definitions of the set of logical constructs, Data Fusion and Visualization systems will be developed in inconsistent ways and will have irregular payoff and benefit to the upper command levels of the operational military. We propose that the Workshop address the various and complex issues dealing with the topic of "logical constructs", and the means by which the NATO community can develop methodologies and architectures for visualizing these "non-physical, non-geospatial/temporal" constructs.

OBJECTIVES

In recent years research in Data Fusion and Visualization science has focused on understanding physical environments and data types. Advanced visualization techniques including VR and other related technologies have succeeded in providing meaningful outputs. However many abstract concepts are beyond traditional modes of display and hence require new paradigms in visualization.

Our objective is to present an organized, provocative introductory presentation regarding the definitions and ontological structure of such non-physical concepts as well as possible means for visualizing/ communicating their states as a framework to encourage lively discussions among military staff and

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research scientists on approaches for both computing the estimated value of and for efficiently communicating/visualizing the results of fusion-based estimates of these conceptual states. Through such discussion, it is hoped that a NATO consensus can be established on the issues surrounding this important topic, and also that agreement can be established on additional research needed to both better understand this topical area and to develop effective visualization/communication methods.

TECHNICAL APPROACH

We are proposing to come to the Workshop with a presentation that elaborates on these issues. The first point is to define further what is meant by "non-physical entities"; in this case we plan to elaborate on the example of "Operational Readiness", and to discuss what is the modern interpretation of this term and the associated concepts. This will lead into a sampling of a draft ontological construct for this term, showing that, as for many such constructs, it is composed of both entities that do have a physical reality but also notional terms that result from abstract and fuzzy constructs. Given this, the challenge of visualization is elaborated on, to show that there are at least two major challenges to visualization: the dimensionality of these constructs, and the non-geospatial, non-temporal elements of them. It is also argued that the need for an ontological-level, formally-constructed characterization of these constructs is central to a consistent systems-level approach to the design of the overall information fusion process. Further, it is shown by example that such ontologically-based design methodologies are not precedent-setting for defense-type applications. Another factor discussed is the distinction between the user's mental model and the visualization-construct, i.e. the "display". Mental models are usually defined as "deep" constructs, reflecting the comprehensive understanding that a human has about a given process or object; the computed and visualized product can be thought of as an instance of that model, but as a result the delivered visualization should draw on the mental model that a user has. But even if that visualization is consistent in this way, there is still the question of how the user visualizes his mental model in his mind – one challenge or hypothesis to explore is whether the "optimal" visualization is a construct that mirrors the user's mental "image" of his model, or whether these two entities are separate and reside in their own separate contexts (i.e. computer-screen and human mind). A nagging question is also: what is "the" authoritative taxonomical structure from which we should build the relevant ontology? By this is meant that, if the US defense community is typical, there are many lists of vocabulary and terminologies that abound in the defense community – if it is agreed that in fact an ontological framework for the terms of interests is needed, which list is the starting point? In this regard, some examples of the US community's "Essential Elements of Information" or "EEI's" are described along with some limited ontological-structuring of these terms that has been carried out. Finally, we give two major examples of visualization techniques that have been used in defense-type applications as exemplars of some modern-day display constructs: these are the "Event Wall" and the "Starlight" systems. These systems have been designed with the idea of showing information of high-dimension and information having complex interrelationships.

Visualizing Non-Physical, Logical Constructs for Command Decision-Making Support

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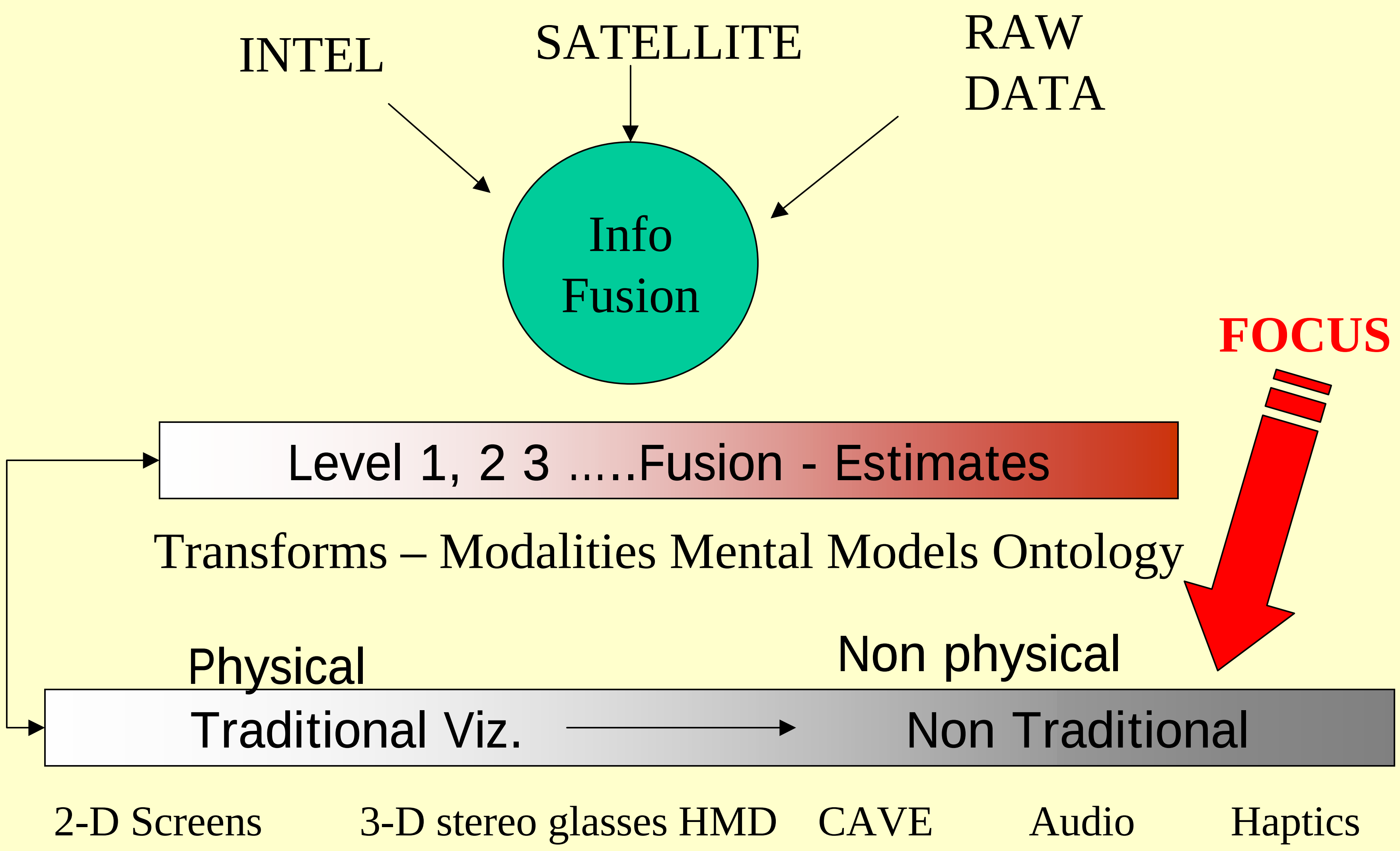
Visualization, Info. Fusion and Logical Constructs



Directions in "Level 2,3" Information Fusion

Defense Planning Guidance And Visions

Network-Centric Warfare

Consistent Operating Picture ("Situation")

Progress in Data and Information Fusion Technologies

Improved Standardization And Formalism in Level 2,3 Info Fusion Engineering Methods

Motivation

- ***Higher-echelon command decision-making*** **depends on information at the *conceptual level*, involving such terms as:**
  - **"Center of Gravity", "Situation", Intent", "Course of Action", "Operational Readiness"…..etc**
- **An integrated and adequately-formalized consensus set of definitions for these terms, *an Ontology*, *suitable for automation*, does not exist.**
- **Such states are ideally estimated via Information Fusion techniques**
- **If it did, and IF we could automatically (or even semi-automatically) *compute multisource-based estimates* of these "states", we have not explored the issue of how to *communicate such states to military decision-makers.***

Discussion Topics

- **Assessment of *Need for Ontological Development* in Support of the Design of "Higher-Level" Information Fusion Processes**

- **Strategies and *Technologies/Techniques for Communicating-Visualizing Fused Estimates* for "Situations", etc**

General Benefits of an Ontology*

- **Consistent knowledge sharing and reuse**
- **Improved understandability**
- **Consensus-building**
- **Information system Interoperability**
- **……**

•Users

•Developers

Basic Ontology

Objects/Concepts
•Properties and Attributes
•Predicate relations

"A Specification of Concepts within a Domain"

→ Statements And/or Axioms Applicable in the Domain

→ Employed in Inference or Algorithmic Applications (eg L2, L3 Fusion

* Eg see Slattery, N.J., "A Study of Ontology and its Uses in Information Technology Systems", Mitre Corp Report

“Non-physical Entities” and the Visualization Challenge

Another "Construct": Operational Readiness

Part of Military Capability:

--Force Structure (Numbers, Composition)

--Technical Sophistication

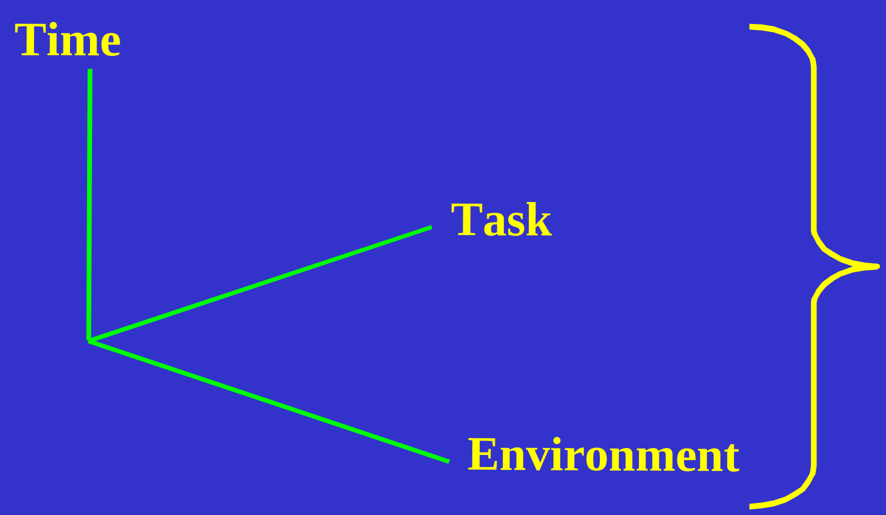
--Readiness

--Sustainability

Readiness in General

As Betts* accurately points out, "The main question for policy and strategy should not be how to achieve readiness in any single sense. Rather, it is how to integrate or balance the answers to the following questions over a long period of time."

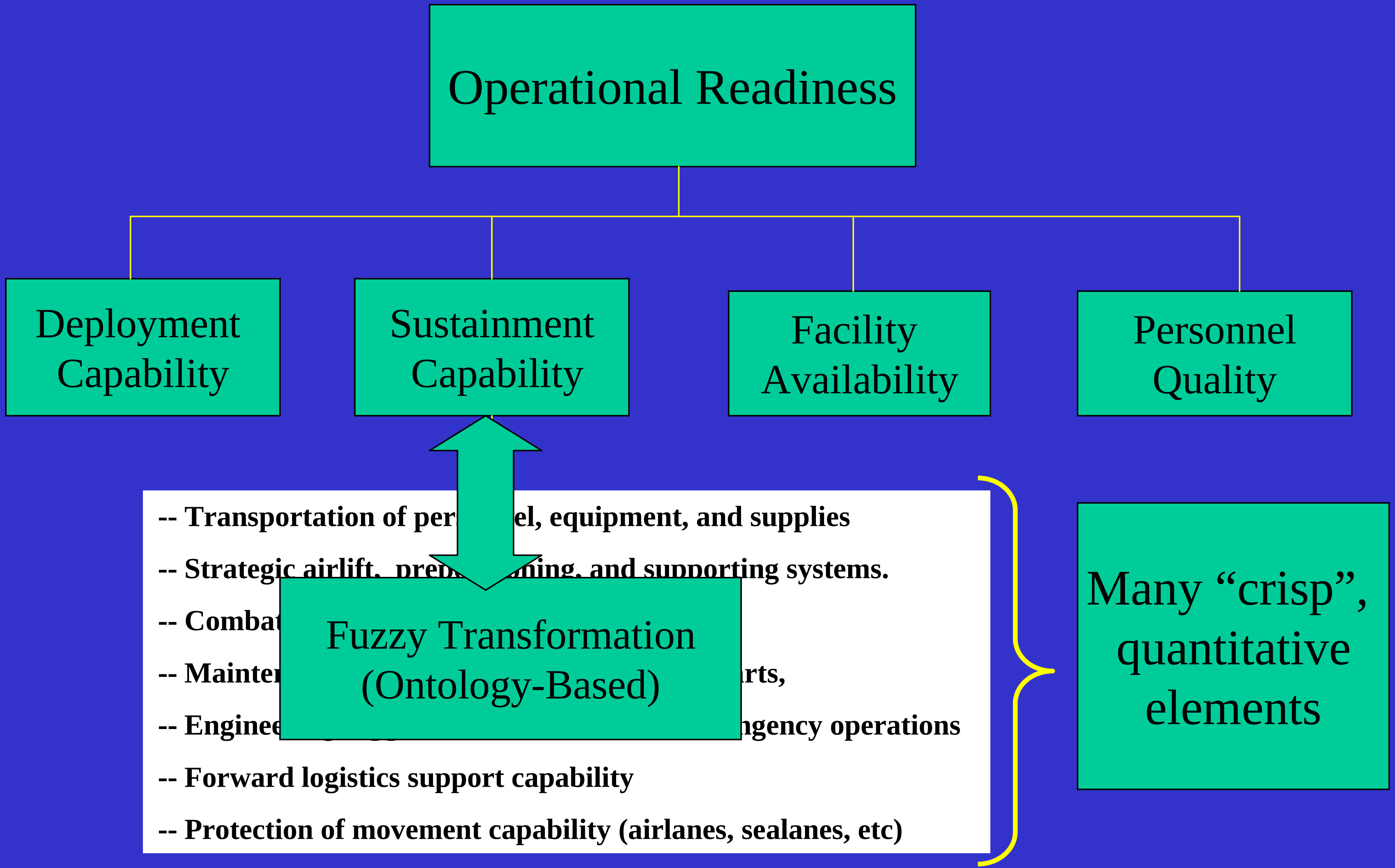
- **Readiness for when? How long to "ready"?**
- **Readiness for what? "Ready" to perform what tasks?**
- **Readiness for where? "Ready" for what theater or combat environment?**



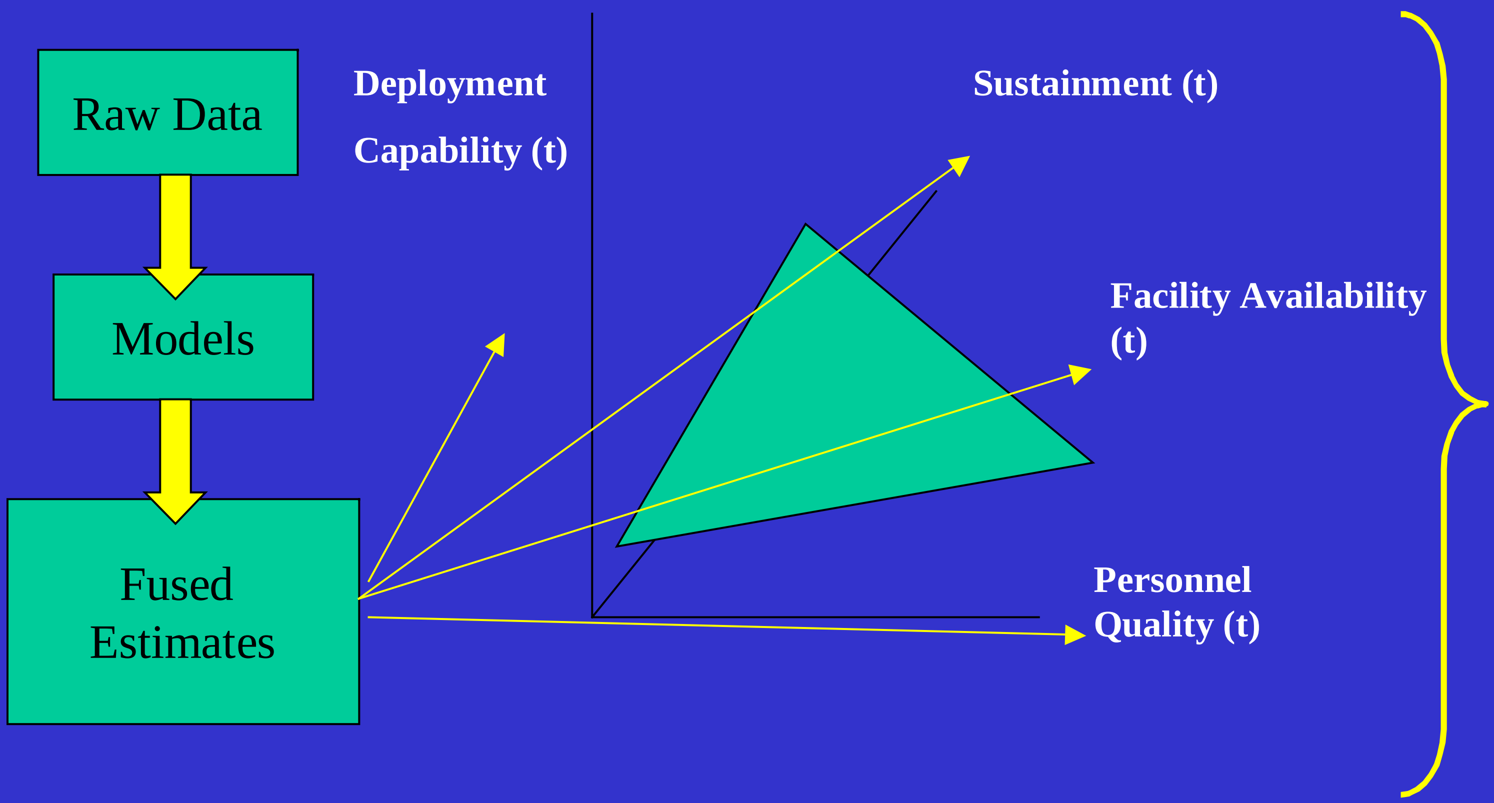
Dimensions in which features of Readiness can be visualized

* Richard K. Betts, *Military Readiness: Concepts, Choices, Consequences* (Washington, D.C.: The Brookings Institution, 1995), 43.

Ontology of Operational Readiness (a notion)



On Operational Readiness



Operational Readiness Features, to be visualized in "7D' for each Task and Environment

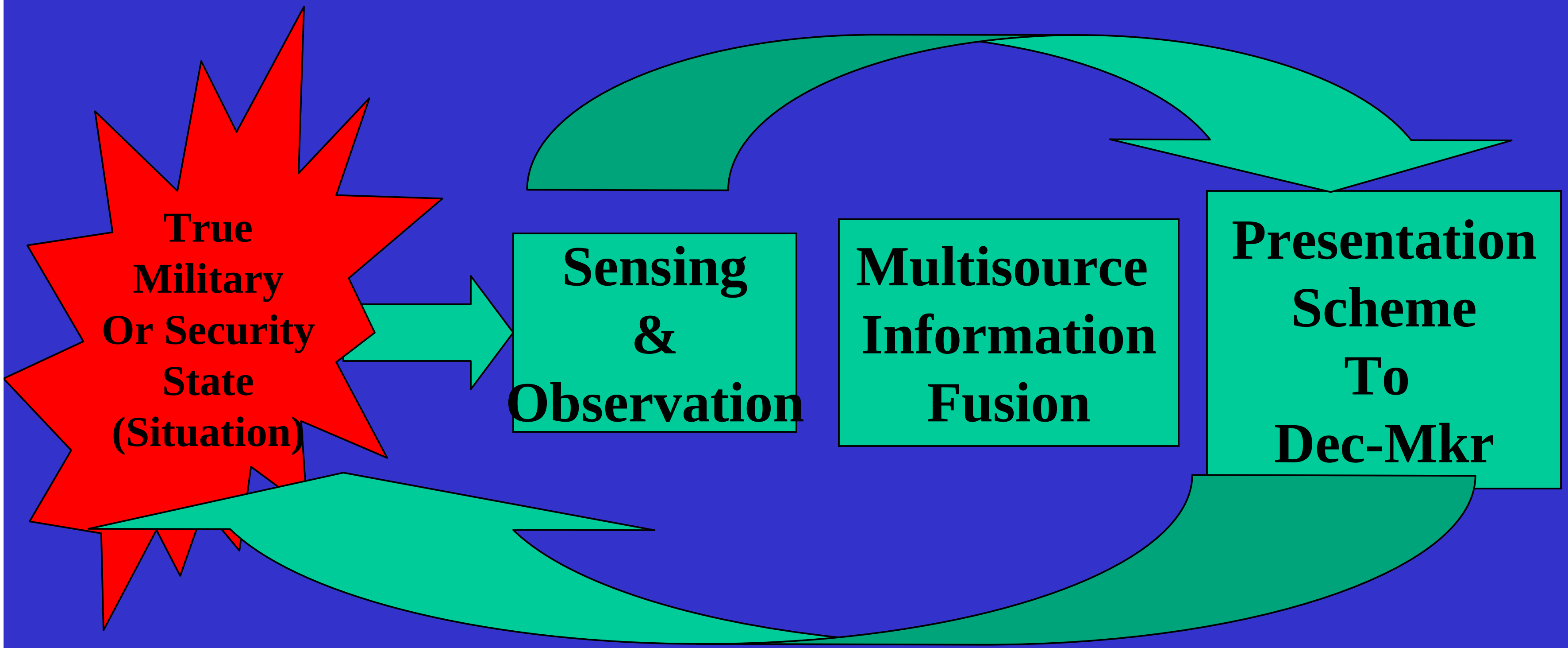
DEFINITIONS OF SITUATIONAL AWARENESS*; MANY VIEWS —

Definitions	Source
Conscious awareness of actions within two mutually embedded four–dimensional envelopes.	(Beringer and Hancock, 1989, p. 646)
A pilot's continuous perception of self and aircraft in relation to the dynamic environment of flight, threats, and mission and the ability to forecast, then execute tasks based on that perception.	(Carroll, 1992)
The ability to extract, integrate, assess, and act upon task–relevant information is a skilled behavior known as situational awareness	(Companion, Corso, Kass, & Herschler, 1990)
The accurate perception of the factors and conditions that affect an aircraft and its flight crew.	(Edens, 1991, p. 7. Schwartz, 1993, uses this definition with "during a defined period of time" at the end.)
The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.	(Endsley, 1990, p. 1–3)
The knowledge that results when attention is allocated to a zone of interest at a level of abstraction.	(Fracker, 1988, p. 102)
The pilot's overall appreciation of his current 'world.'	(Gibson & Garrett, 1990, p. 7–1)
One's ability to remain aware of everything that is happening at the same time and to integrate that sense of awareness into what one is doing at the moment.	(Haines and Flateau, 1992, p. 43)
Where refers to spatial awareness...**what** characterizes identity awareness, or the pilot's knowledge of the presence of threats and their objectives, [as well as] engine status and flight performance parameters. **Who** is associated with responsibility, or automation awareness that is knowledge of who's in charge. Finally, **when** signifies temporal awareness and addresses knowledge of events as the mission evolves.	(Harwood, Barnett, and Wickens, 1988, p. 316)
The ability to envision the current and near–term disposition of both friendly and enemy forces.	(Masters, McTaggart, and Green, 1986, p. 5; Stiffler, 1987)
Awareness of conditions and threats in the immediate surroundings.	(Monsnige and Retelle, 1985, p. 92)

* From Cohen, MS, etal. "A Cognitive Framework for Battlefield Commander's Situation Assessment", U.S. Army Res Inst for Behavior and Soc Sci. Tech Rpt 1002, July 1994

(From the Human Engrg literature)

A Notional Processing Chain



Defined components **of the Situation (the Ontology) set the basis for :**

--Sensor design

--Processing design

--Presentation scheme

i.e.—the entire system design

Another Example: SA via Plan Recognition Approach Using an Ontology

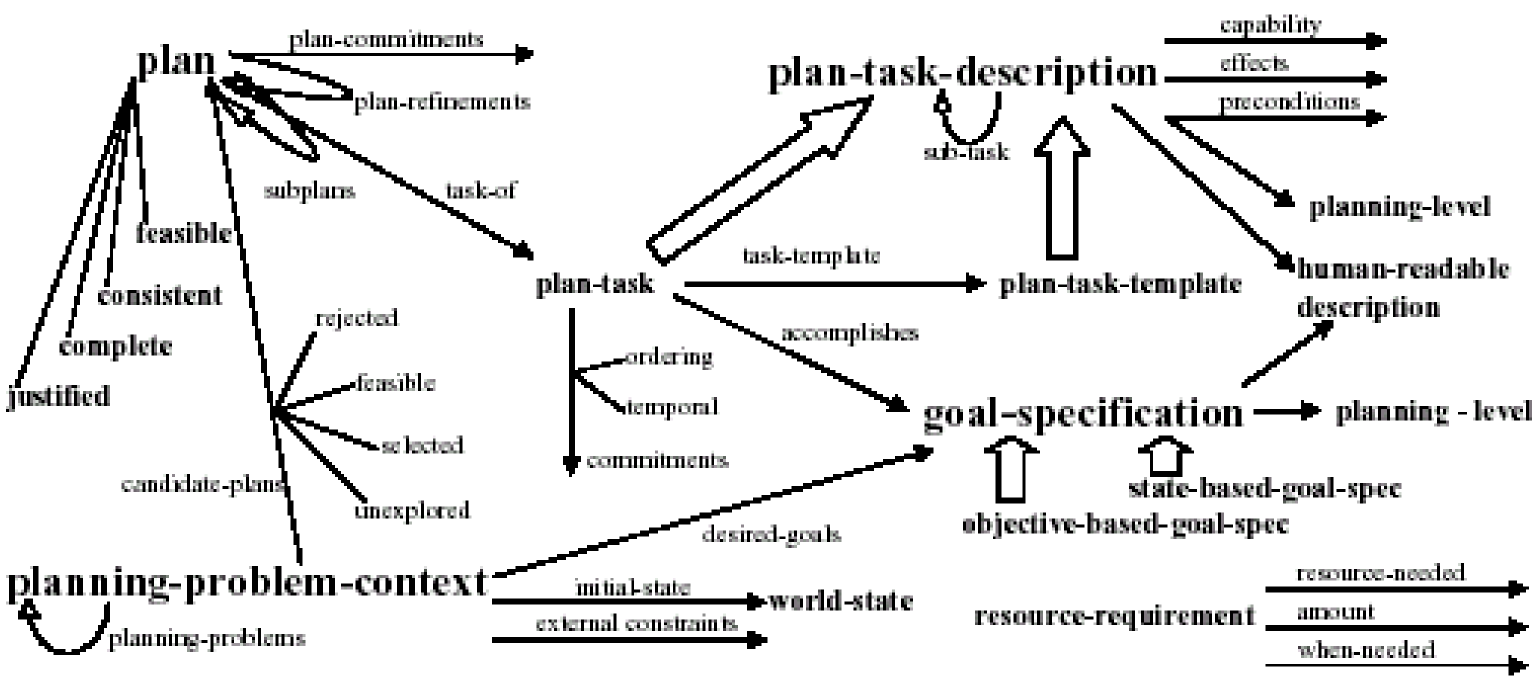


Figure 1: An overview of the PLANET ontology. Arrows pointing into space represent relations whose ranges are not fixed in the ontology.

From: PLANET: A Shareable and Reusable Ontology for Representing Plans, Yolanda Gil and Jim Blythe

University of Southern California / Information Sciences Institute, Marina del Rey, CA, USA

Consideration of "Definitions" Includes (Is?) the User's Mental Model

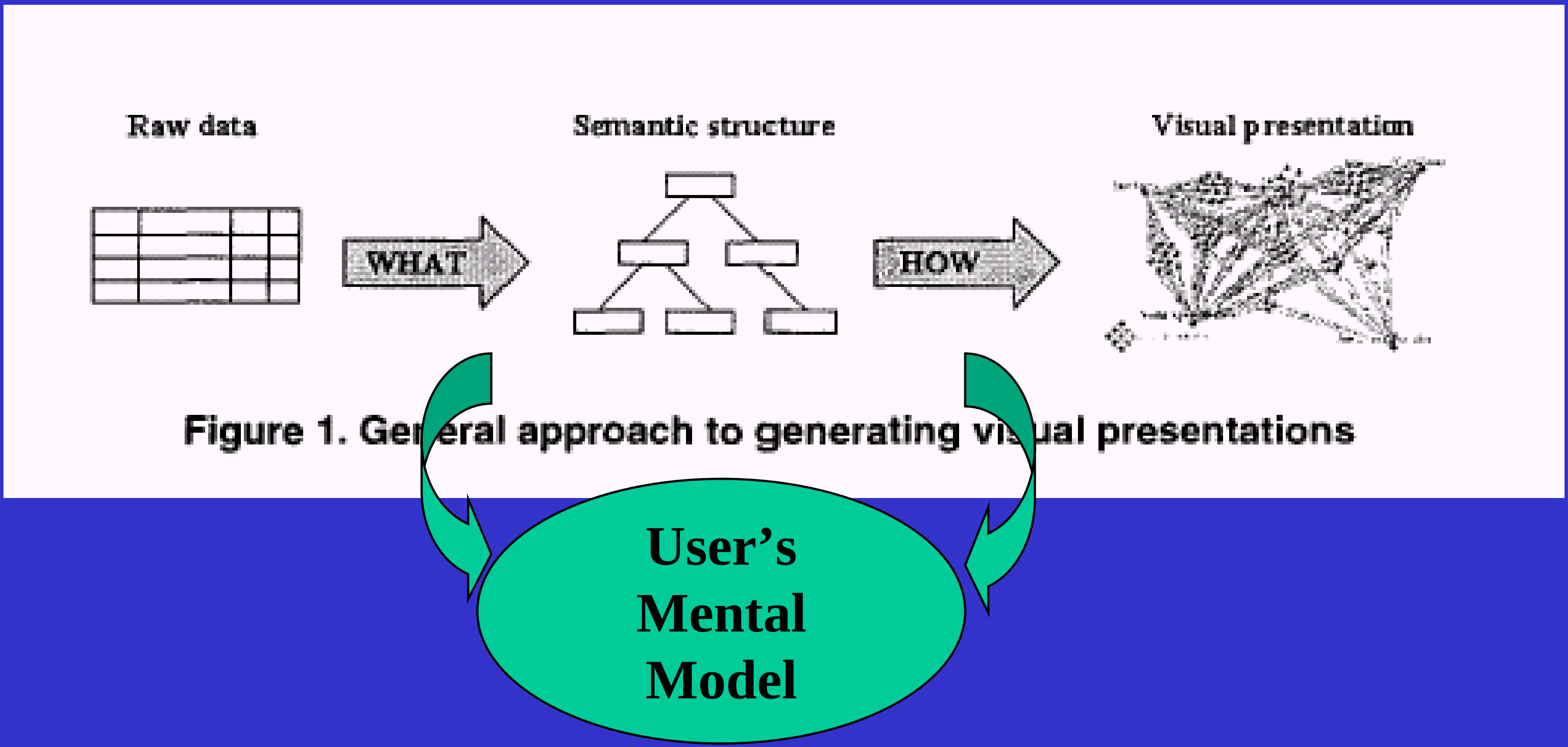
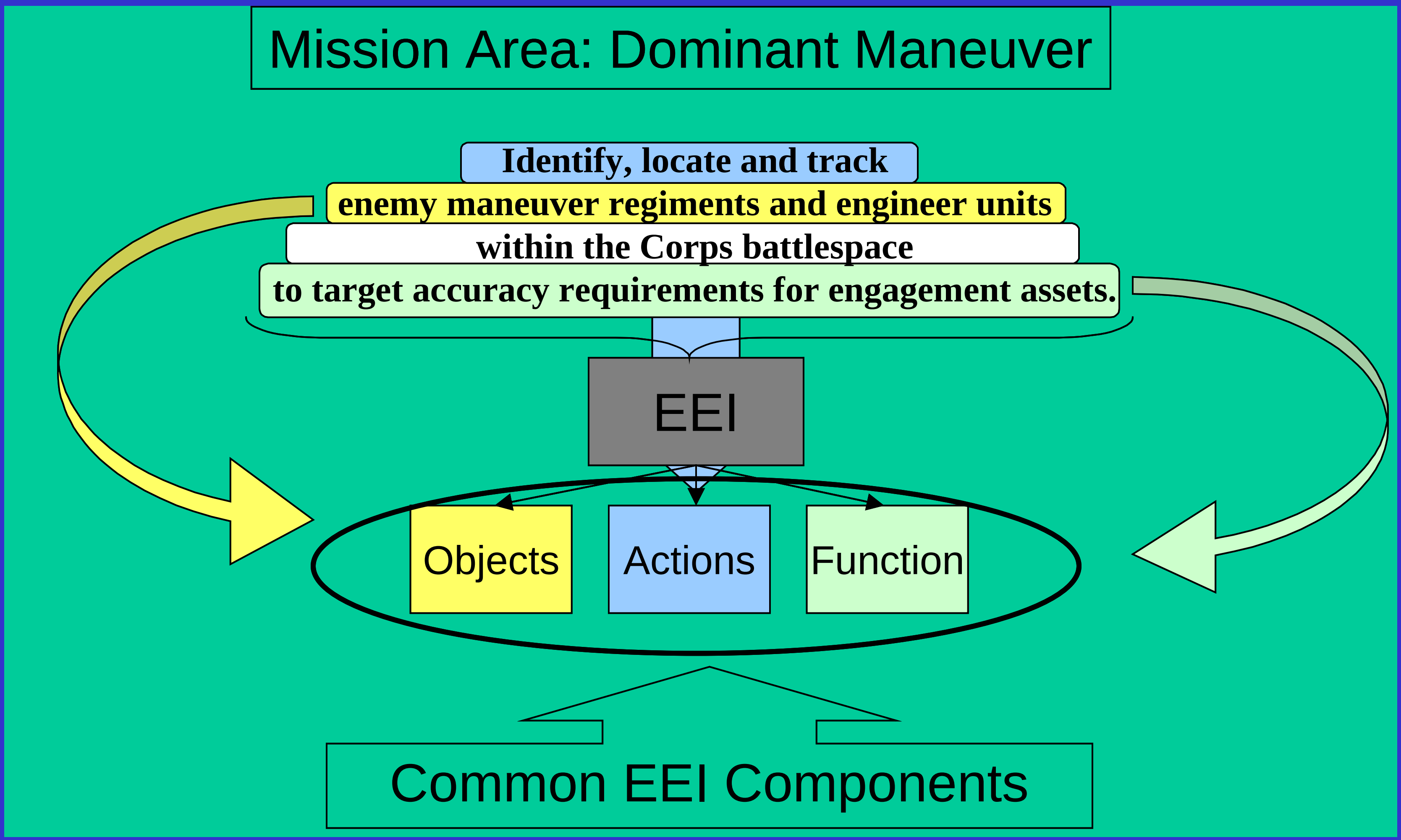


Figure 1. General approach to generating visual presentations

From: Ontology-based Information Visualization, van Harmelen et al, Vrije Universiteit, Amsterdam

One Approach: Use Essential Elements of Information (EEI's)



Expanding the EEI's

Functions

I&W	– Indications and Warning
IPB	– Intelligence Preparation of the Battlespace
FP	– Force Protection
SD	– Situation Development
TGT	– Targeting
BDA	– Battle Damage Assessment

Objects

Order of Battle (OB)	– Forces, hierarchies
Facilities/Infrastructure	– Non-moving objects
Geospatial	– Natural objects
Networks	– Information, logistics
Political	– Individual and organizations

Actions

Detect – What is it?
Location – Where is it?
Track – How is it moving?
Identity – Who is it?
Status/Act. – What is it doing?
Capability – What can it do?
Intent – Who, What, When, Where, How,Why?

Another Factor: Temporal Dynamics—Requirements for Visualizing Temporal Scenes

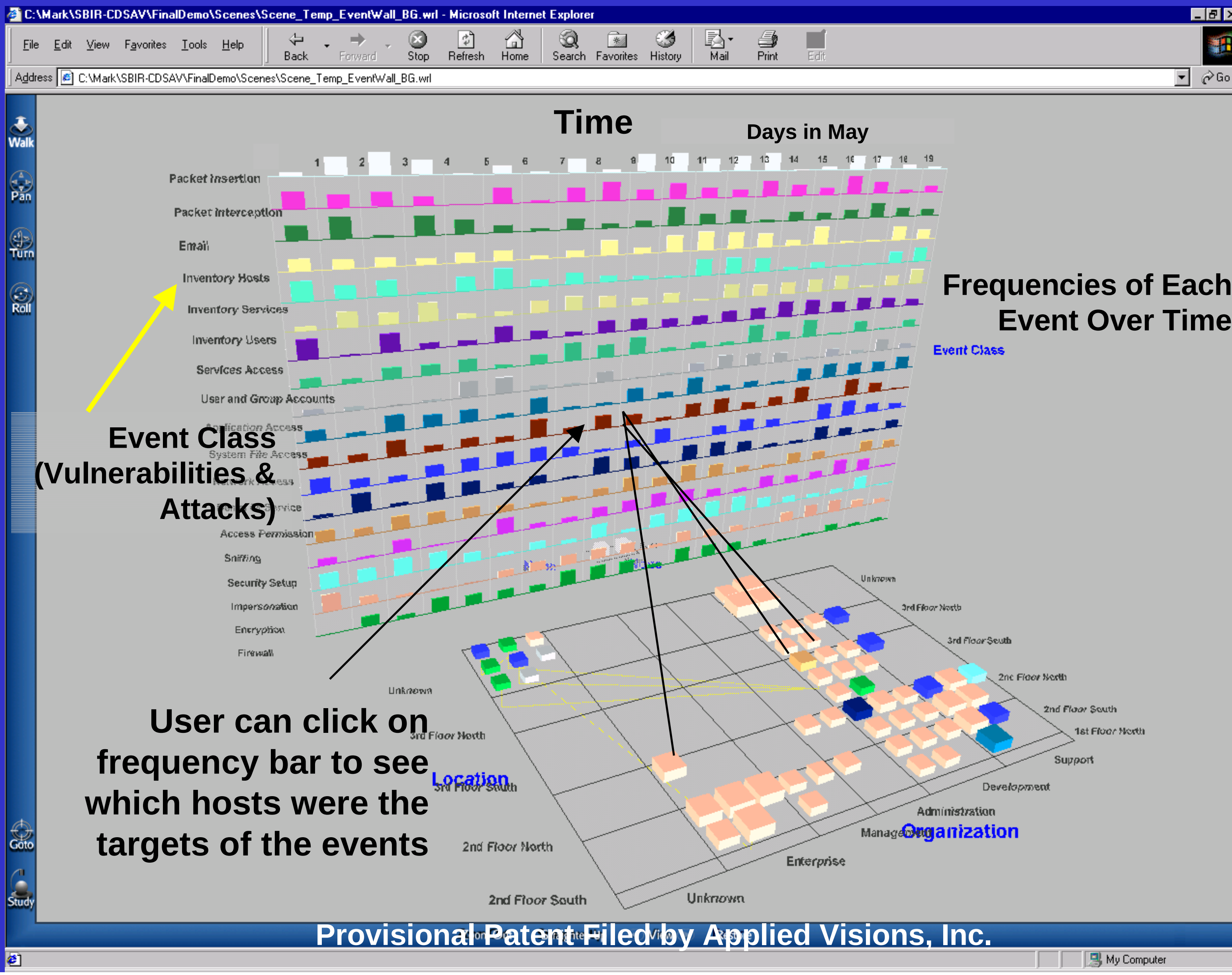
- User-selectable time gradations
- User-selectable time range
- User ability to annotate time grid
- Relate security events and their characteristics to time
- Relate attack sources and their characteristics to time
- Relate targeted assets and their characteristics to time
- Simultaneously relate events, attack sources and target characteristics to time

OK—now assume Level 2, 3 Info Fusion Capabilities exist and have been developed from an Ontologically-Based Approach….
How do we Visualize these Complex (“ND”) Notions??

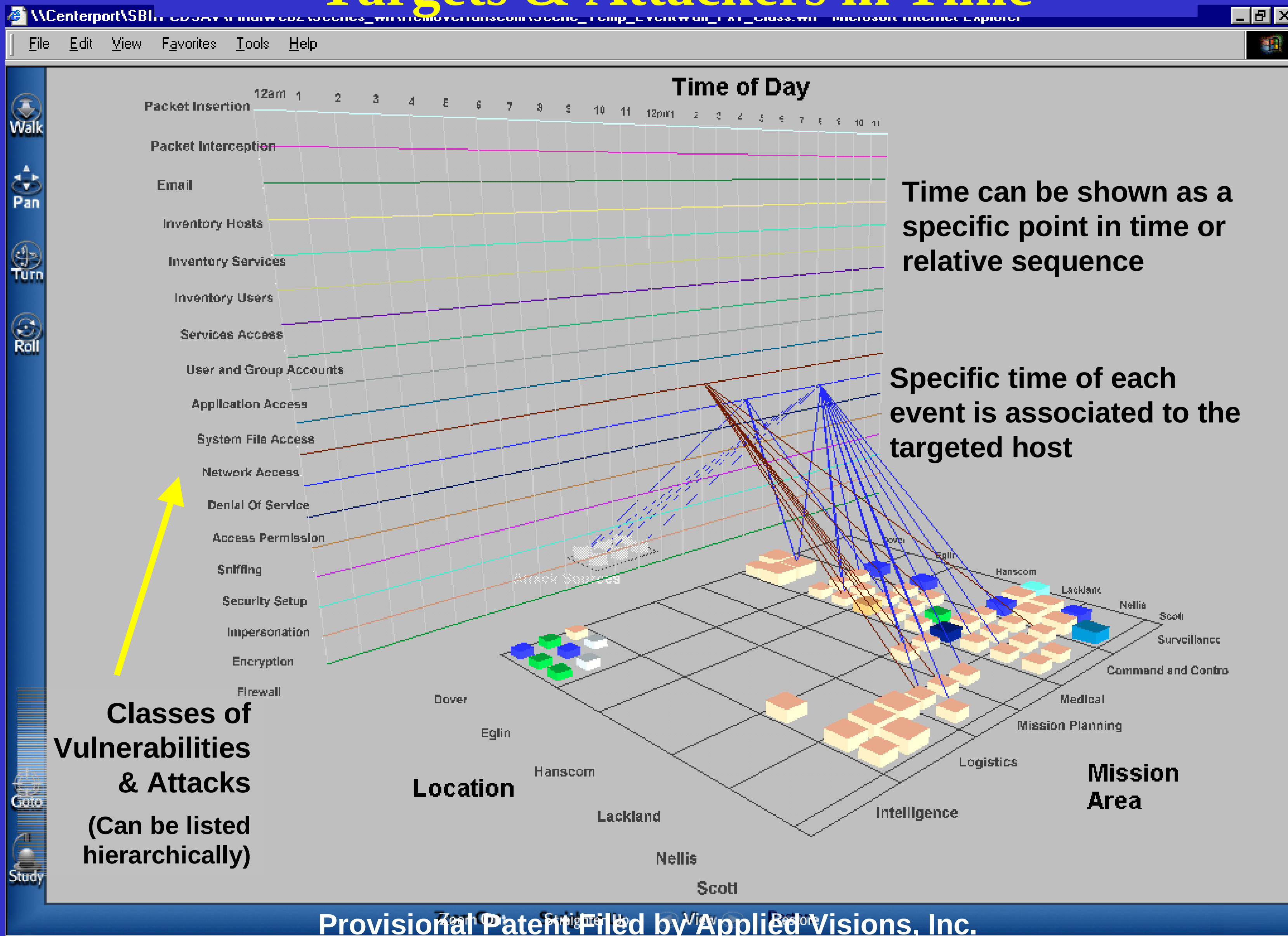
One Approach:
The “Event Wall”

(Secure Decisions, Inc.)

Temporal Event Wall Can Display Event Frequencies, Sequences & Durations



Event Wall Scene Links Events, Targets & Attackers in Time



Time can be shown as a specific point in time or relative sequence

Specific time of each event is associated to the targeted host

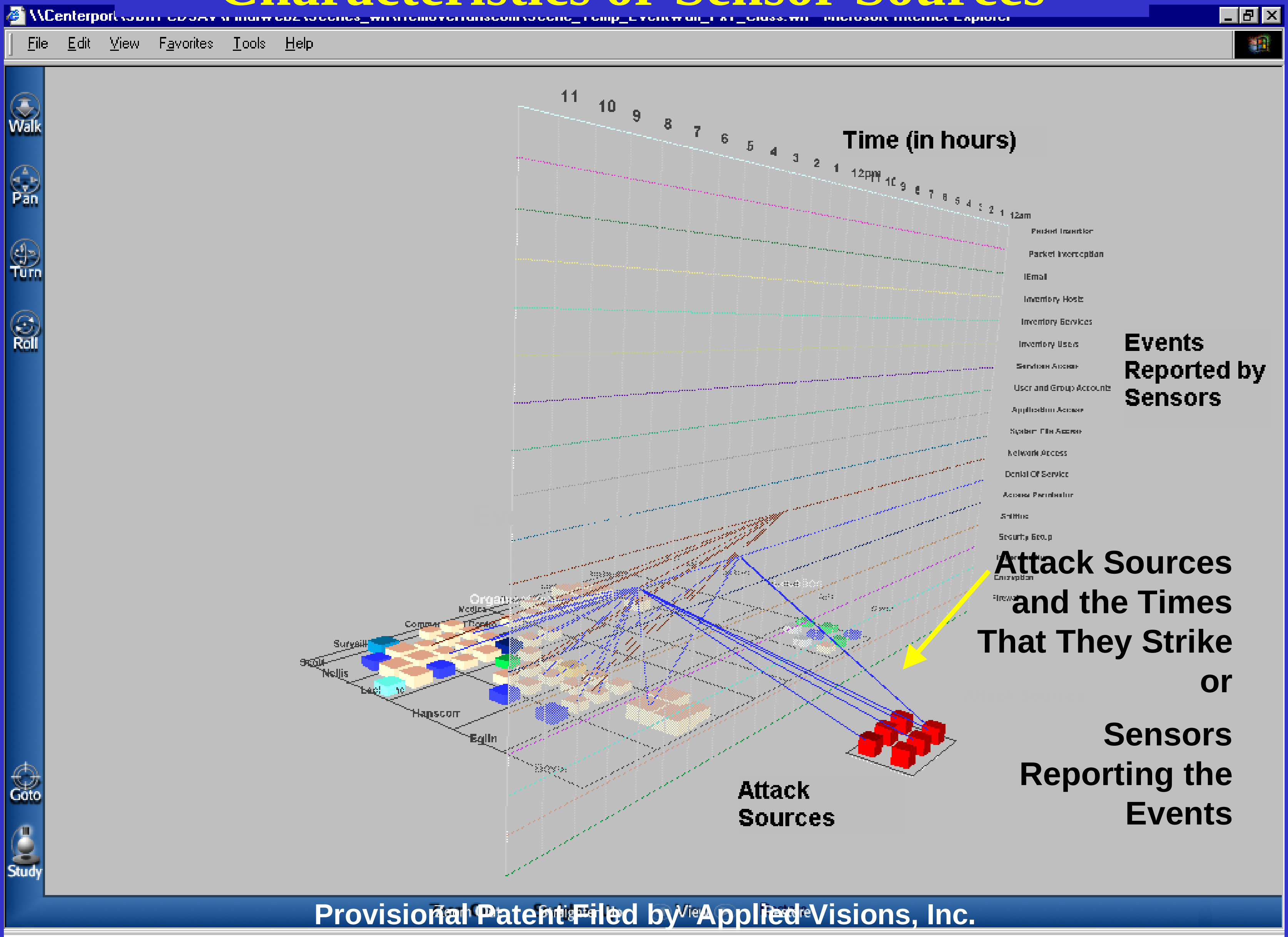
Classes of Vulnerabilities & Attacks

(Can be listed hierarchically)

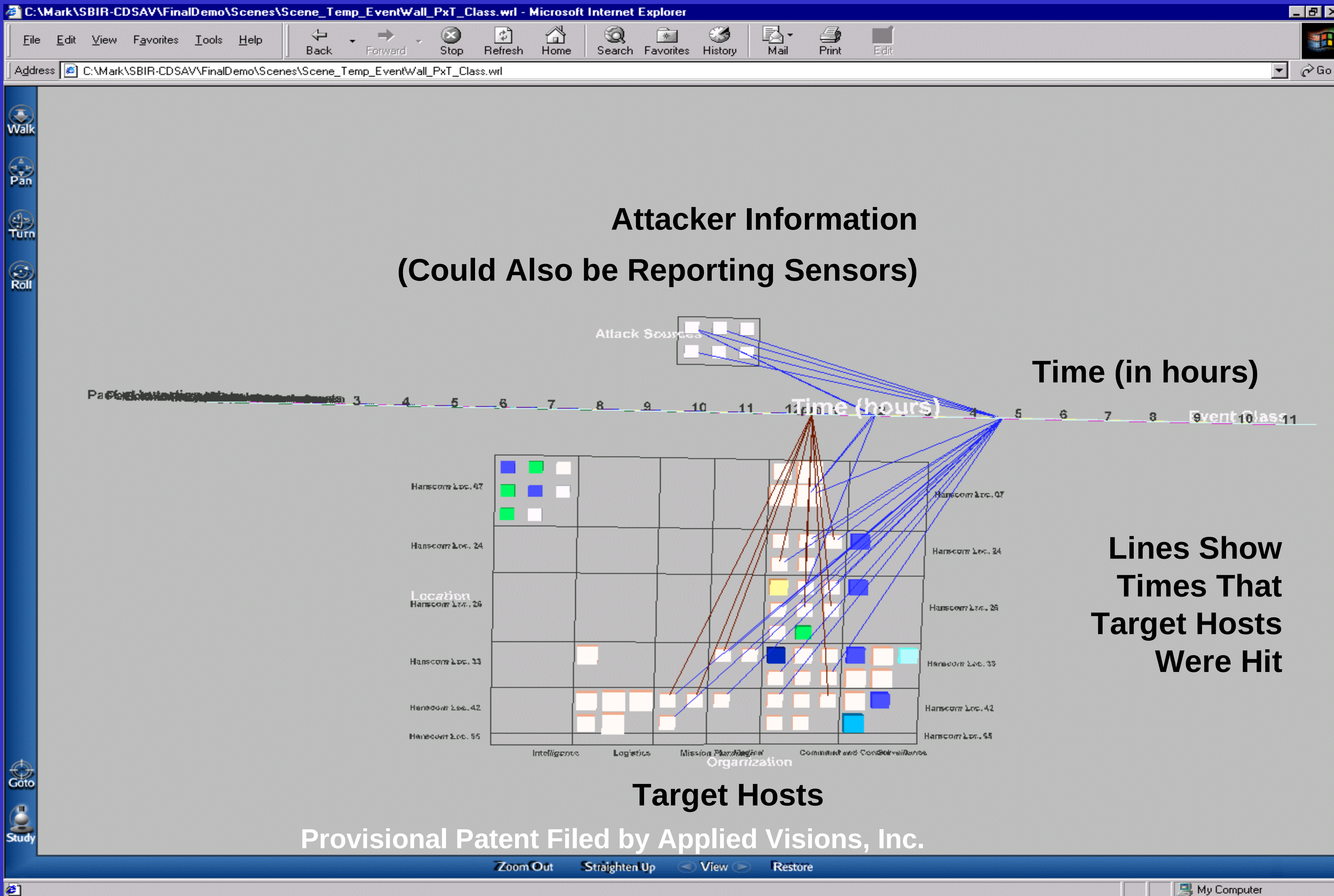
Location

Mission Area

Rear Plane Can Show Attacker Characteristics or Sensor Sources



Top View Allows Simultaneous Viewing of Activities Related to Time

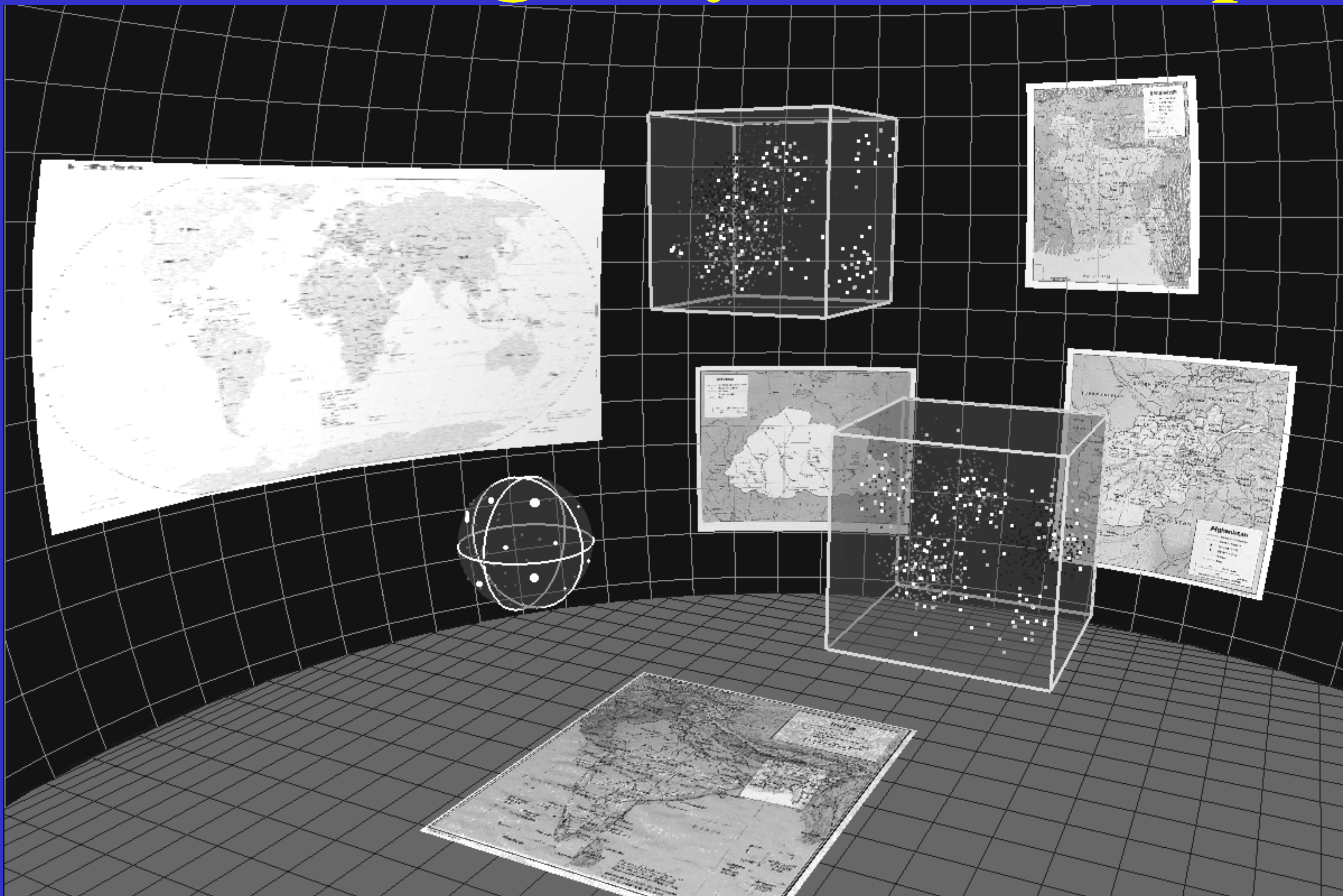


Another Approach: “Starlight”

(Pacific Northwest National Labs.)

Exploring and analyzing of large and complex collections of multimedia information, structured an unstructured text, geographic information and digital imagery.

The Starlight System Example



From: The *STARLIGHT* Information Visualization System, JS Risch, DB Rex, ST Dowson, TB Walters, RA May, BD Moon, Pacific Northwest National Laboratory, Richland, Washington USA

The Starlight System Example, cont'd

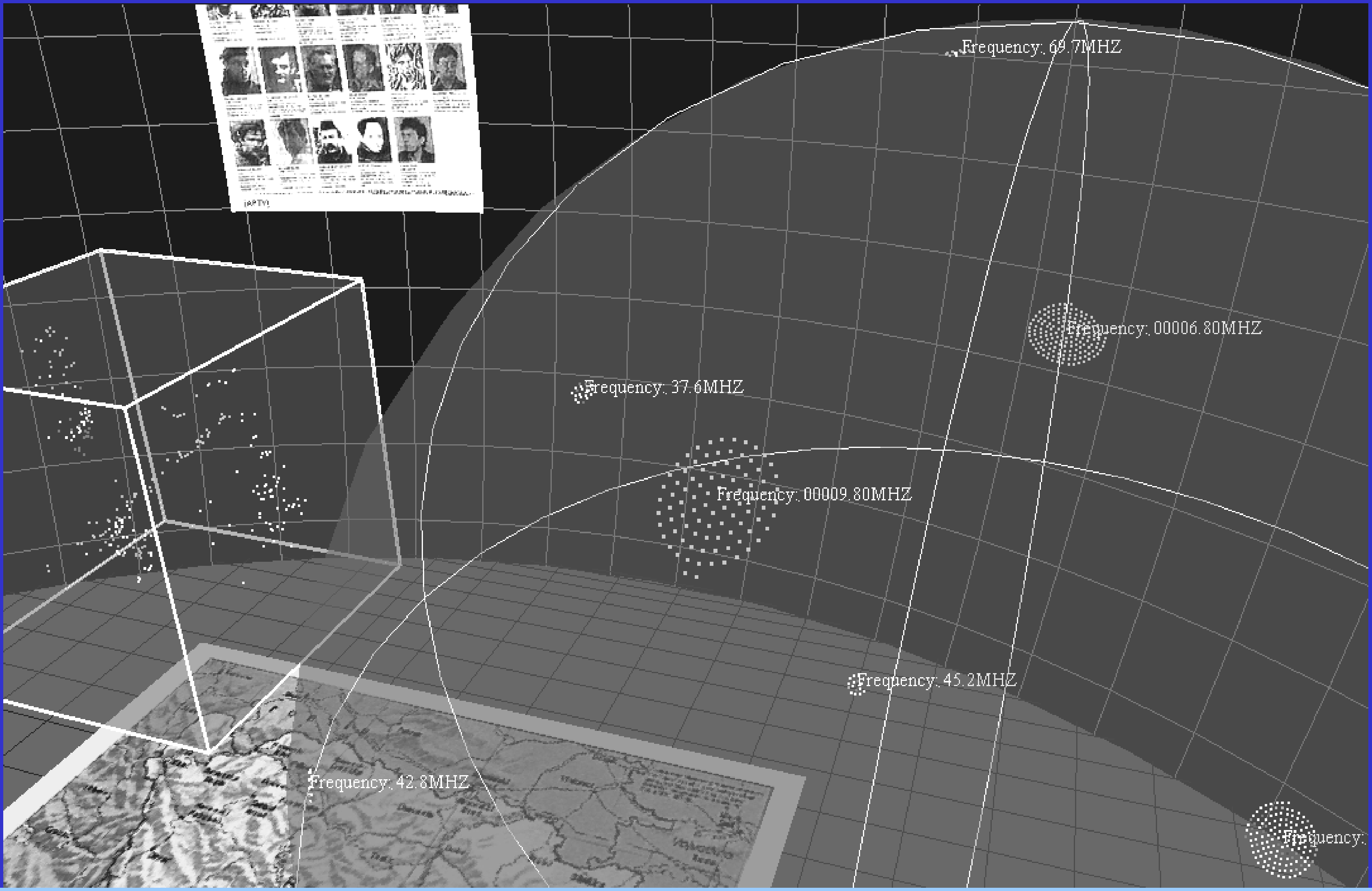


Figure 2. Close-up view of a *Data Sphere* showing structured data set elements grouped according to the values in a given field.

The Starlight System Example, cont'd

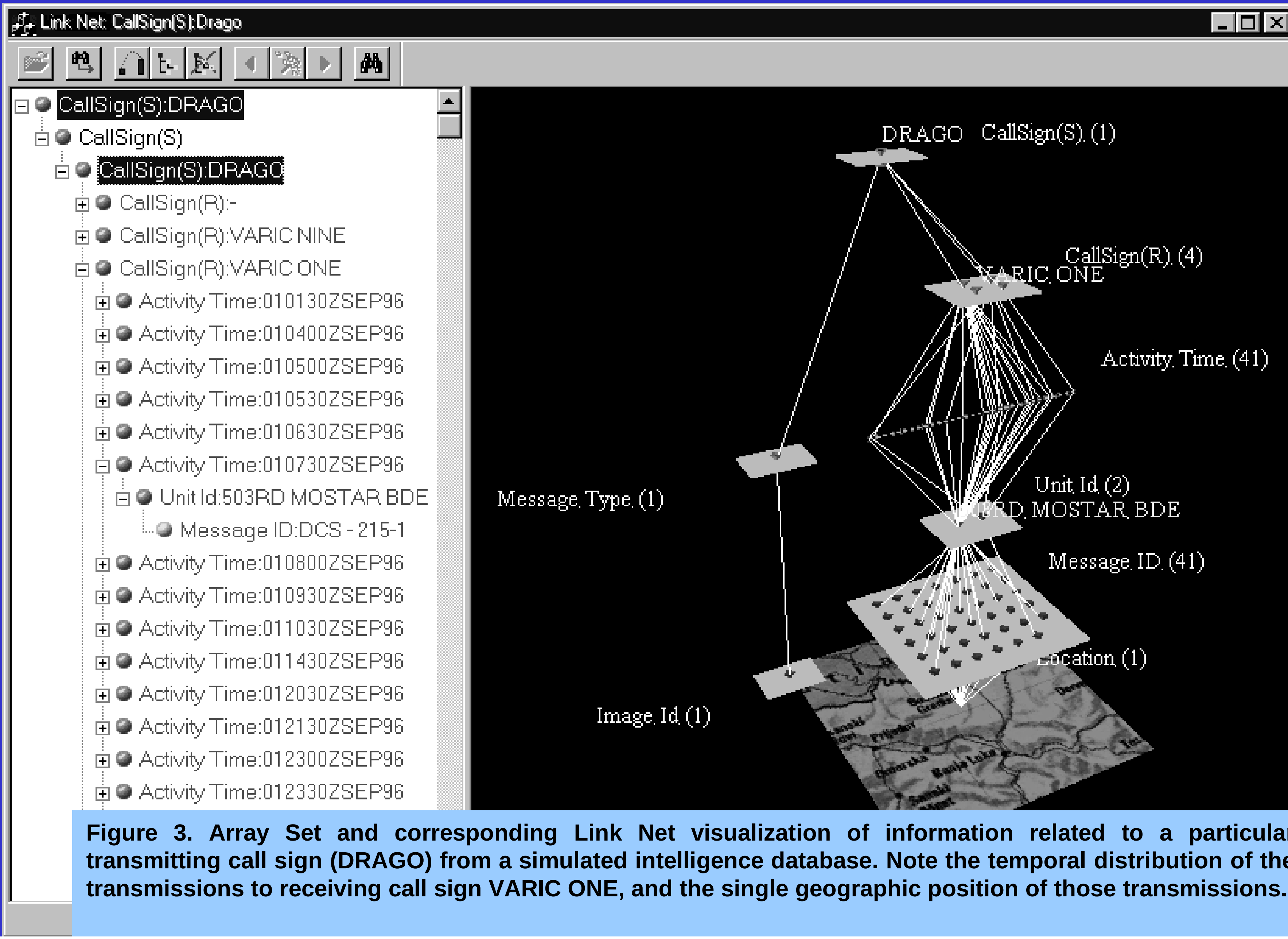


Figure 3. Array Set and corresponding Link Net visualization of information related to a particular transmitting call sign (DRAGO) from a simulated intelligence database. Note the temporal distribution of the transmissions to receiving call sign VARIC ONE, and the single geographic position of those transmissions.

The Starlight System Example, cont’d

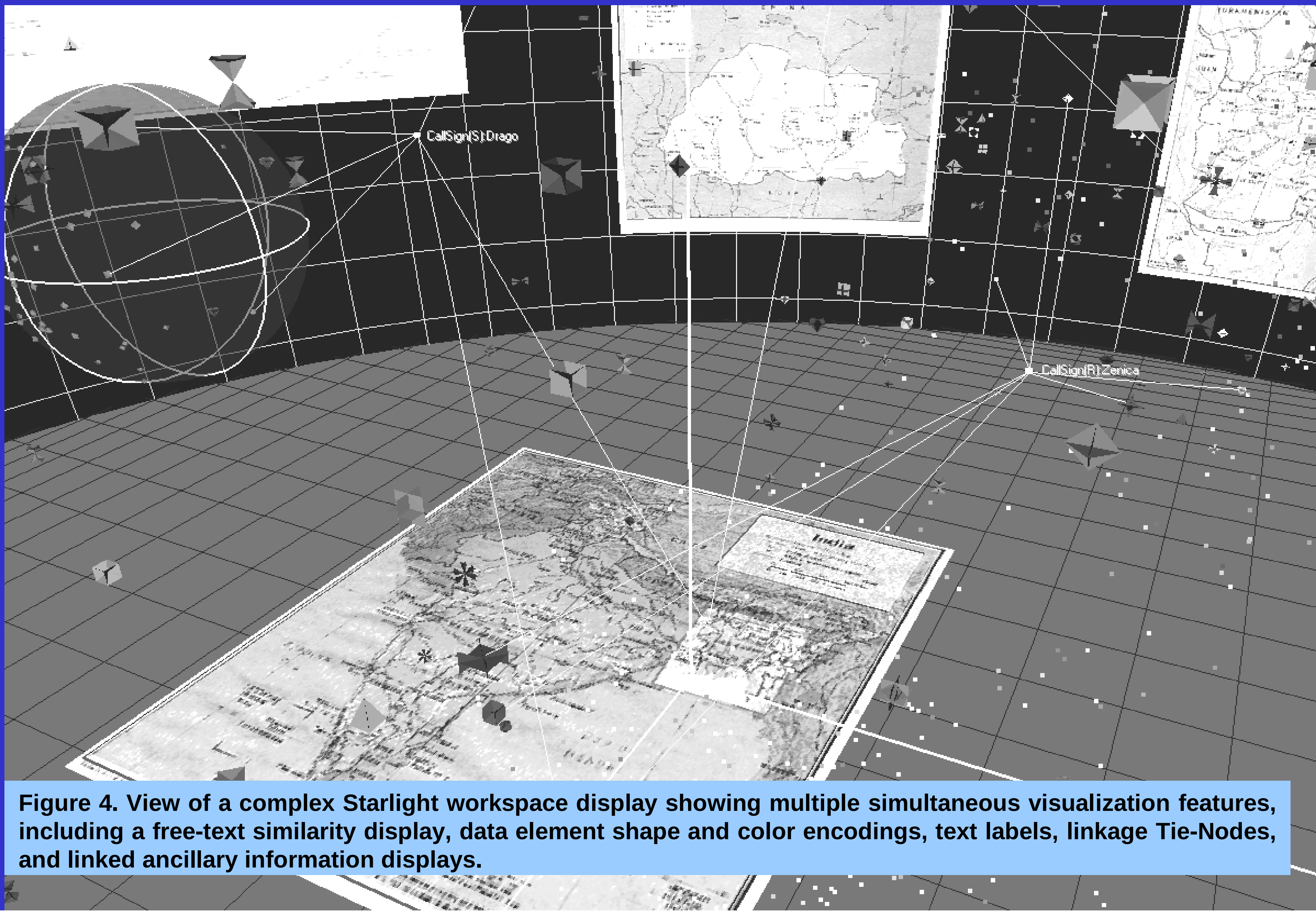


Figure 4. View of a complex Starlight workspace display showing multiple simultaneous visualization features, including a free-text similarity display, data element shape and color encodings, text labels, linkage Tie-Nodes, and linked ancillary information displays.

Backups etc

Ontological Aspects of Fusion L1 Terms

<u>Class:</u>	A number of objects that share general characteristics. (i.e. , maneuver unit, vehicles, surface ships, fixed-wing aircraft, building)
<u>Type:</u>	A class of objects that share particular characteristics. (i.e. tank unit, AAV, destroyer, fighter, aircraft hangar)
<u>Model:</u>	A style or design of a particular type of object; mode of structure or formation. (i.e. tank company, AAV C-7, DDG-21, F-14, aircraft 3rd echelon maintenance facility)
<u>Composition:</u>	The specific parts or elements that form an object. Composition can refer to the material and structural composition of a building or the composition of networks. (i.e. hierarchy of organizations, personnel & equipment, material structure of a building)

Ontological Aspects of Fusion
L2 Terms

Definition: **Capability is the capacity and ability of an object to execute courses of action or functions based upon knowledge of an object's factors and circumstances.**

Additional Definitions:

Ability: Competence and power to perform a course of action.
Capacity: Actual or potential ability to perform a course of action.
Function: The appropriate or assigned duties, responsibilities, missions, or tasks of an individual, office, or organization (facility). *(JP1-02)*
Influence: The capacity or power of objects to be a compelling force on or produce effects on the actions of others.

*Factors & circumstances include but are not limited to the following: ***composition, doctrine, environment, equipment/materials, maneuverability, mobility, morale, numbers, readiness, technical sophistication, size, sustainability, and weapons systems.*** *(JP1-02)*

Ontological Aspects of Fusion L2 Terms

<u>Definition:</u> Activity is the collection of actions or events associated with an object. State is the status of an object.

<u>Additional Definitions:</u>

<u>Event</u>:	A happening or an occurrence
<u>State</u>:	The condition of an object with respect to certain attributes and circumstances
<u>Attributes:</u>	Qualities or characteristics of an object
<u>Circumstances</u>:	Condition, detail, or attributes with respect to time, place, or manner that determine an event or action
<u>Linkage</u>:	The relationship of two or more activities which can be associated with an object
<u>Determine:</u>	To settle or decide a question by an authoritative or conclusive decision